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PULSE CODE MODULATION OF VIDEO SIGNALS: Subjective effect of random digit errors

No. 1972/14

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

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(EL-63)

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PULSE CODE MODULATION OF VIDEO SIGNALS: SUBJECTIVE EFFECT OF RANDOM DIGIT ERRORS

Summary

This report describes subjective tests performed to establish the maximum allowable error rate in a p.c.m. system handling PAL colour and monochrome 625-line television signals. Both random single-digit errors and burst errors were examined. The tests included an investigation of a system for concealing errors based on the use of parity bits. The results showed that, with no error concealment in use, the picture impairment was negligible if the error rate was no greater than 1 in 10^7, *similar results being obtained for both single-digit and burst errors; with error concealment in use, the error rate should not be greater than 1 in* 10^4 *for single-digit errors or 1 in* 10^5 *for burst errors having a duration of less than 1 μs.*

1. Introduction

When a pulse code modulation (p.c.m.) signal is transmitted through a communication circuit, some digits may be incorrectly detected at the receiving terminal through the presence of noise or distortion in the received signal. This report describes subjective tests performed to determine the picture impairment produced by digit errors in a p.c.m. system handling System I, monochrome or PAL-colour, 625-line video signals.

The p.c.m. signal was obtained by sampling the video signal at a rate of 13·3 MHz and converting the magnitude of each sample into an 8-bit binary number. The code 00000000 represented the level at the bottom of synchronising pulses and 11111111 represented the highest level reached by the video signal. With such a code, if a '0' is incorrectly received as a '1', a 'white-going' error pulse is introduced into the decoded video signal; alternatively, if a '1' is received as a '0', a 'black-going' pulse is obtained.

The investigations included tests in which the effect of errors was concealed by a technique based on an error detection system involving the addition of a single parity digit per sample. Concealment was achieved by replacing samples containing an error by a sample corresponding to an adjacent picture element.

The report is concerned with the impairment caused by both random single-digit errors (i.e. errors which are randomly distributed in time, each error affecting only one digit), and errors which affect many successive digits, often referred to as 'burst' errors. Since very little is known concerning the most likely duration and time distribution of burst errors on a video p.c.m. link, it was not thought worthwhile to carry out extensive tests on their subjective effect at the present time. However, an indication of the effect of burst errors was obtained using randomly distributed groups of errors lasting for 120 digits, i.e. about 1 μs. Also, the effect of errors with a duration of 3–12 μs can be deduced from the results of subjective tests on the impairment caused by drop-outs on video tape recordings,[1] and an analysis of these results is included.

In order to introduce known error rates and known error durations into the p.c.m. signal, it was found to be more convenient to use a pseudo-random error generator controlled by a steady train of clock pulses rather than to generate errors from a truly random source.

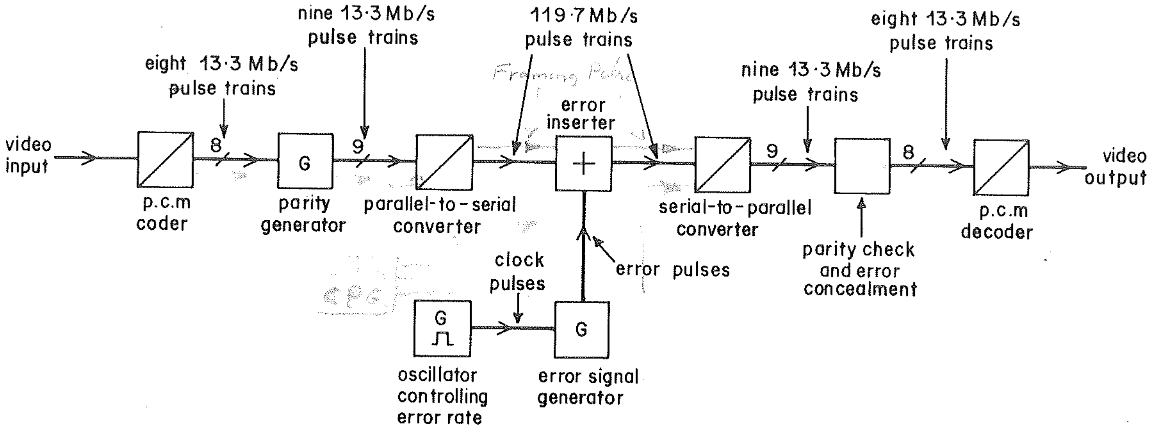
eight 13·3 Mb/s pulse trains
nine 13·3 Mb/s pulse trains
119·7 Mb/s pulse trains
Framing Pulse
nine 13·3 Mb/s pulse trains
eight 13·3 Mb/s pulse trains
video input
8
G
9
error inserter
+
9
8
video output
p.c.m coder
parity generator
parallel-to-serial converter
serial-to-parallel converter
parity check and error concealment
p.c.m decoder
clock pulses
error pulses
EPG
G
G
oscillator controlling error rate
error signal generator

Fig. 1 - Block diagram of equipment used in subjective tests

2. Equipment used for inserting and concealing errors

2.1. General

A block diagram of the equipment used to insert and conceal errors in the p.c.m. signal is shown in Fig. 1. The p.c.m. coder and decoder have been described in a previous report.[2] The coder operated at a sampling rate of 13·3 MHz and provided 8 bits per sample in parallel at eight separate outputs. This parallel form of signal was also required at the input of the p.c.m. decoder. However, in order to simulate errors on a transmission link it is more convenient to insert errors into a serial rather than a parallel form of digital signal. For this reason, parallel-to-serial and serial-to-parallel converters[3] were included before and after the error inserter unit; this latter unit is discussed in Section 2.3.

In the parity generator, a single parity digit was derived for each sample, giving a total of nine digits per sample. This unit was provided with 8 on/off switches which enabled the parity sum to be applied to any combination of the 8 digits in a sample. The parity checking unit was provided with corresponding switches which had to be set to the same positions as those used in the parity generator. The parity checking unit also contained the circuits for concealing the effect of errors detected by means of parity violation. Further details of the error concealment system are given in Section 2.4.

The mean frequency of the errors was controlled by an oscillator which fed a regular train of clock pulses to the error signal generator. This generator derived a pseudo-random sequence of error pulses as discussed below in Section 2.2.

2.2. Error signal generator

In the generator, the input clock pulses were applied to a 25-stage shift register with feedback taken from the 22nd and 25th stages via an exclusive OR gate to the input of the first stage. With such a feedback system, the output of any stage of the shift register consists of a 'maximal-length' pseudo-random sequence of 0's and 1's, the sequence being repeated after every $2^{25} - 1$ (i.e. $33{\cdot}5 \times 10^6$) clock pulses. If this sequence were used directly as the error signal, the mean time between error pulses, as indicated by the presence of 1's, would be two clock pulse periods and the minimum time would be one clock pulse period. To increase the randomness of the errors, the outputs from 7 different stages of the shift register were fed to an AND gate, the output of which was used as the error signal. The mean time between the error pulses thus obtained is equal to 128 (i.e. 2^7) clock pulse periods and the minimum time remains at one clock pulse period. Using this system, the maximum clock frequency at which the shift register would operate limited the maximum obtainable error rate to about 1 error pulse for every 2000 digits of the 120 Mb/s PCM signal. To obtain higher error rates the number of inputs to the AND gate was reduced to 6 or 3 thus increasing the maximum error rate by a factor of 2 or 16 respectively.

One difference between the pseudo-random error signal described above and a truly random signal which should be noted is that the pseudo-random signal never causes two or more separate errors in the protected bits of one sample; such errors should be considered since if the protected bits in one sample contain an even number of errors, the parity rule is not violated and the errors are not detected. This difference is only significant, however, at high error rates and the additional impairment which would be obtained with a truly random signal as a result of these undetected errors can be allowed for in the manner described in Section 4.3.

2.3. Error inserter unit

On receipt of an error pulse, this unit caused an error whose duration could be varied so that it affected any number of digits between one and about 200. The type of error could be altered so that the affected digits were either (a) complemented (i.e. '0's changed to 1's and vice versa) or (b) all set to '1' or (c) all set to '0'.

In the subjective tests, condition (a) was used for single-digit errors, and conditions (b) and (c) for burst errors. The reasons for this choice of conditions are as follows:

In practice, single-digit errors are most likely to be caused by the addition of random noise to the p.c.m. signal and this effect would cause digits to be complemented. On the other hand, burst errors are most likely to be caused by impulsive interference which would set all digits during a single impulse to the same state.

2.4. Error concealment

Two methods of concealing errors were developed. In the first method, samples in error were replaced by the last good sample received before the commencement of the error. This technique gave a marked reduction in the impairment caused by single-digit errors on monochrome pictures. With colour pictures, however, less satisfactory results were obtained since the presence of large-amplitude colour subcarrier causes significant differences in the analogue signal level between successive samples. To overcome this difficulty, a second concealment system was developed[4] which made use of the fact that the sampling rate used in the tests was close to three times colour subcarrier frequency. By replacing an incorrect sample by the sample which occurs three sampling periods earlier, information is taken from the correct part of the subcarrier cycle: this system will be referred to as the 'third-previous sample' method of concealment.

During burst errors, the three samples obtained prior to the error were repeated in succession, thus maintaining the phase and amplitude of any subcarrier present in the video signal before the error commenced. Further, the samples which preceded and followed a burst error were assumed to be in error; this overcomes the difficulty that there is a reasonably high probability that there will be no violation of the parity rule for the first and last samples affected by a burst error. The presence of a burst error is indicated when two or more successive samples are found to be in error.

Only the third previous sample method of concealment was used in the subjective tests because it gave much better concealment of errors than the previous sample system in areas of a picture containing saturated colours and was only very slightly inferior in unsaturated areas.

If the sampling rate is not exactly equal to three times subcarrier frequency, the substitute samples obtained with the third-previous sample method will not be precisely correct in plain coloured areas of a picture. If the sampling frequency is 2·8% different from three times subcarrier frequency, then the maximum difference between every third sample in a plain field of 100% saturated cyan will be equal to an error in the fourth most significant bit. Initial tests indicated that digital errors in the fourth and subsequent bits caused negligible impairment on a 100% colour bar picture with error rates as high as 1 in 1000. It was therefore concluded that the results obtained from the tests will apply for any sampling frequency which is within about 2·8% of three times subcarrier frequency, but further tests would be required for sampling frequencies outside this range.

3. Subjective tests: description

3.1. General

The video signals obtained from the output of the PCM decoder shown in Fig. 1 were displayed on a high quality 19 in. colour monitor having a peak brightness of 55 candelas/metre^2 (16 ft-L); with zero beam current, the brightness of the screen resulting from ambient illumination was 0·1 candelas/metre^2 (0·03 ft-L). In the coder, the video signal was clamped with the tips of synchronising pulses at the bottom of the conversion range and its amplitude adjusted so that 100% saturated colour subcarrier would just reach the top of the conversion range (see Fig. 2).

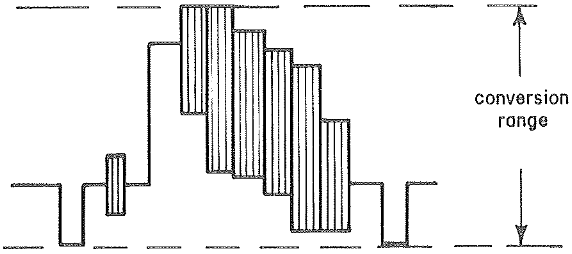

Fig. 2 - Adjustment of video levels relative to the conversion range of the coder, shown for 100% colour bar signal

For the purpose of the present tests, arrangements were made to introduce error-free synchronising pulses and colour bursts into the decoded video signal thus avoiding timing or clamping errors caused by digital errors in the line and field blanking intervals. In normal circumstances when no error-free signal would be available, such errors could always be substantially removed by relatively simple video processing techniques.

3.2. Signal source

Both monochrome and colour pictures were used in the tests, the signal sources being:—

(a) A 35 mm colour slide scanner containing a slide of which a monochrome version is shown in Fig. 3. Both monochrome and colour versions were shown in the tests.

Fig. 3 - Monochrome version of slide used in tests

(b) A video tape recorder replaying a recording of a musical variety programme called 'Music, Music, Music'. The pictures (obtained from cameras) were typical of good-quality, highly-coloured light entertainment.

(c) A high-quality receiver providing off-air colour pictures obtained from a good quality demonstration film used for 'trade tests'.

These were selected as being fairly typical sources of both moving and stationary pictures provided by a high-quality broadcasting service.

3.3. Test procedure

Each test condition was shown to two separate groups of six observers seated at a mean distance of six times picture height from the monitor. At any one sitting, judgements were obtained on 15 different test conditions, each being shown twice with other conditions in between. The observers were all engineers having previous experience of assessing picture quality.

The degradation in picture quality caused by digital errors was graded using the EBU 6-point impairment scale, with additional verbal descriptions in parenthesis, as shown below.

Grade	Degree of Impairment
1	Imperceptible (No impairment)
2	Just perceptible (Negligible impairment)
3	Definitely perceptible but not disturbing (Slight impairment)
4	Somewhat objectionable (Marked impairment)
5	Definitely objectionable (Severe impairment)
6	Unusable (Complete impairment)

The additional comments in parenthesis were added to avoid a slightly confusing aspect of the normal scale with the type of impairment caused by errors. For example, single errors separated by long intervals might be 'definitely perceptible' at their moments of occurrence, yet, because of their infrequency, they constitute too trivial an impairment to merit the comparatively adverse assessment implied by grade 3. These comments were originally used in subjective tests on the impairment caused by drop-outs in video tape recordings,[1] for which a similar confusion can arise.

4. Results of subjective tests

4.1. General

The results of the tests are shown in Figs. 4 to 9. The horizontal axes in all these figures are calibrated in terms of the probability of an error in any one digit; thus, an error probability of 10^{-4} is equivalent to 1 error in 10^4 digits. In the figures concerned with error concealment systems, 'Bit 1' refers to the most significant digit (M.S.D.) in a word describing a sample and 'Bit 8' refers to the least significant digit (L.S.D.).

In assessing allowable error rates, acceptable picture quality has been assumed to correspond to impairment grades equal to or lower than grade 1·5.

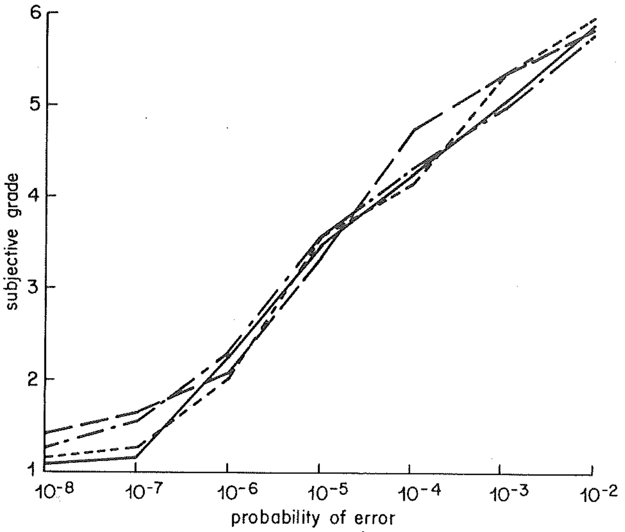

Fig. 4 - Impairment produced by random single-digit errors; no error concealment

——— Slide; colour
—·— Slide; monochrome
— — — Colour film; off-air
- - - - Video-tape recording

4.2. Random single-digit errors without concealment

The results obtained for this type of error are shown in Fig. 4. It will be seen that the impairment corresponding to a given probability of error was very similar for both monochrome and colour pictures and also for still and moving pictures. These results indicate that for acceptable picture quality, the probability of an error should not be greater than about 10^{-7} with no error concealment in use. This figure of 10^{-7} was also obtained in similar work in Japan.[5]

4.3. Random single-digit errors with concealment

Tests were carried out with error concealment based on parity protection of various numbers of bits in each sample. The results obtained are shown in Figs. 5 and 6. It can be seen from Fig. 5 that, on a colour picture from a slide scanner, the impairment for a given error probability was a minimum with parity protection on only the 3 most significant digits. With moving pictures, initial tests indicated that least impairment was obtained with either 3 or 4 bits protected and only these two types of protection were shown to the panel of observers; the results obtained are given in Fig. 6. Subsidiary tests showed that similar results are obtained with monochrome pictures.

The reason for the higher grading obtained with parity protection on more than 3 or 4 bits is that the impairment produced by replacing samples containing errors in bits of low significance is more noticeable than the impairment

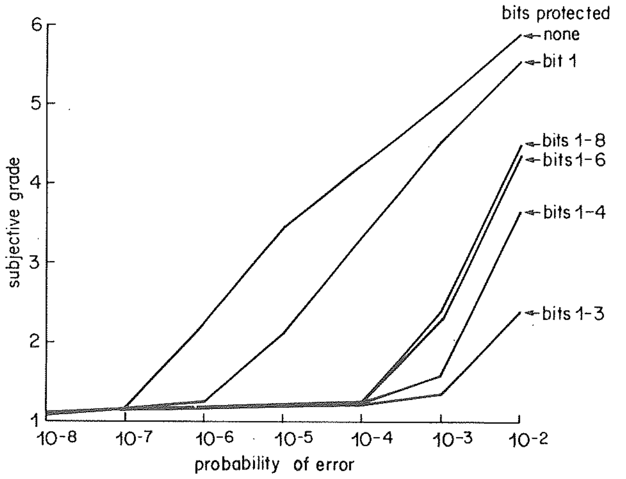

Fig. 5 - Impairment produced by single-digit errors using error concealment

Picture: Colour slide. Bit 1 = MSD; Bit 8 = LSD

produced if such errors are left concealed. Using protection on only a few bits also has the advantage that it reduces the probability of two errors occurring in the protected bits of any one sample; such double errors would not violate the parity rule and would therefore not be detected. This latter effect was not noticed in the tests however, since the minimum interval between errors was equal to one period of the clock pulses fed to the pseudo-random error generator (see Section 2.2) and this was always greater than the interval between successive samples. To make an allowance for the additional impairment that would be obtained with truly random errors, the probability of double errors for a given error rate was calculated and the corresponding impairment was estimated from the results obtained for unconcealed errors. The effect of this additional impairment was calculated using an impairment summing technique similar to that given in Ref. 6. The corrected mean grades for all picture sources are shown in Fig. 7. This figure indicates that, with error correction in use, acceptable picture quality will be obtained if the probability of random single-digit errors is no greater than 10^{-4}.

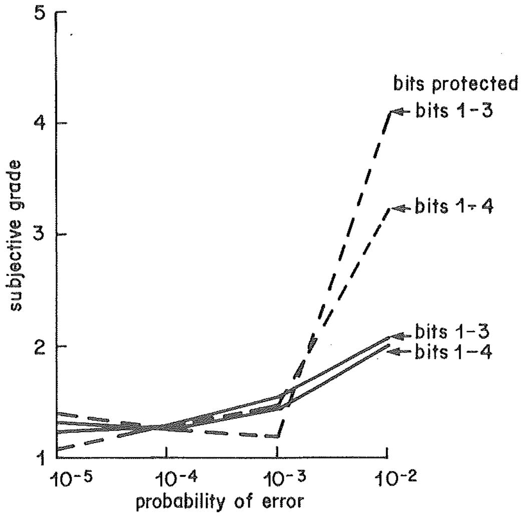

Fig. 6 - Impairment produced by single-digit errors with error concealment in use — Moving pictures

- - - - Video-tape pictures ——— Colour film; off-air

4.4. Random 'burst' errors; no concealment

To obtain an indication of the impairment caused by 'burst' errors i.e. errors affecting many successive digits, subjective tests were performed in which each error pulse set all the following 120 digits either to the '1' state or to the '0' state, only one of these two different types of error being used in a given test; since the video p.c.m. bit-rate was 120 Mb/s, 120 bits corresponds to a duration of 1 μs. The effect of setting digits to '1' was to produce white horizontal dashes on the picture; setting to '0' produced black dashes. The impairments produced by burst errors were found to be very similar for both stationary and moving pictures. The mean grades obtained for both types of picture are shown in Fig. 8 together with the mean grades obtained for single-digit errors. The figure also includes results deduced from tests to determine the impairments caused by 3, 6 and 13 μs drop-outs in conventional video tape recordings of monochrome pictures;[1] these results only covered impairment grades in the range 1·5 to 2·5. In these tests, the signal level during a drop-out excursed to a voltage level 10% above white level, thus producing an almost identical effect to setting all digits in the p.c.m. system of the '1' state for the same duration.

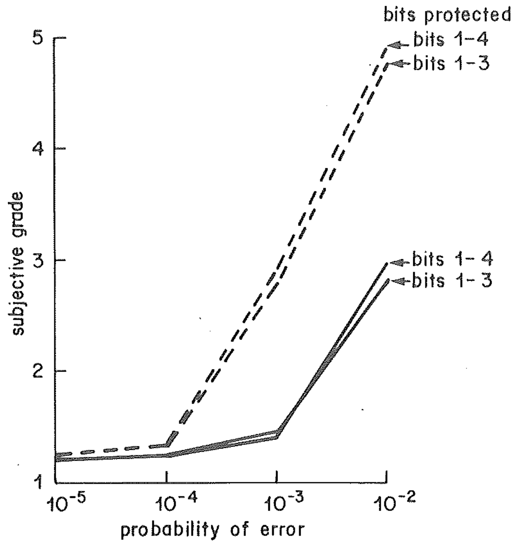

Fig. 7 - Corrected results for single-digit errors to allow for effect of two errors per sample on parity protection system: mean grades for all picture sources

- - - - Results corrected for effect of double errors

——— Uncorrected results

The results given in Fig. 8 indicate that, with no error concealment, acceptable picture quality will be obtained if not more than 1 in 10^7 bits are in error; this result applies to both single-digit and burst errors. The degree of impairment appears to decrease slightly as the duration of the errors is increased, although more comprehensive tests would be needed to confirm this conclusion. Further, it would appear that black errors must occur about 5 to 10 times a frequently as white errors for a given degree of impairment; in the work concerning drop-outs,[1] the value of this ratio was found to be 'about 3 times'.

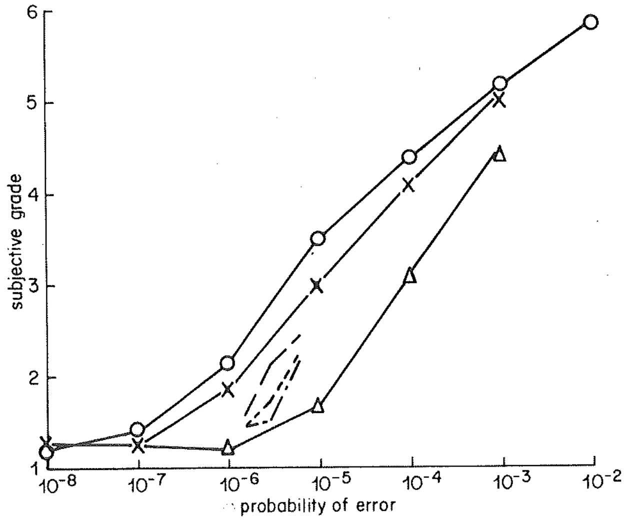

Fig. 8 - Impairment produced by errors of different durations; no error concealment

o Single digit errors — Mean grade for all sources shown in Fig. 1
x White 1 µs errors } Mean grades for still and moving
Δ Black 1 µs errors } colour pictures
— — — White 3 µs errors } Results of tests on
- - - - - White 6 µs errors } 'drop-outs' in converted video-
— · — White 12 µs errors } tape recording (monochrome)

In calculating the error probability for burst errors, it was assumed that all bits occurring during the error were incorrect. An alternative assumption would be that only half these bits were in error since, on average, half of them would already be in the state to which they were set by the error; the effect of a 2 to 1 change in error rate is quite small, however, and would not affect the conclusions given above. In order that the results obtained should not be too critical, the pictures used for the drop-out tests were deliberately chosen to have 'some measure of interest to the observer and the tests were therefore carried out using moving pictures, with sound'. These represent less critical conditions than those used in the p.c.m. tests.

4.5. Random burst errors with concealment

The results of tests on the impairment caused by 1 µs burst errors concealed by the technique described in Section 2.4, are shown in Fig. 9. This figure shows an appreciable difference between the impairments observed on stationary and moving pictures. With the most critical picture (i.e. the coloured slide), acceptable picture quality was obtained provided that the error probability was no greater than about 10^{-5}.

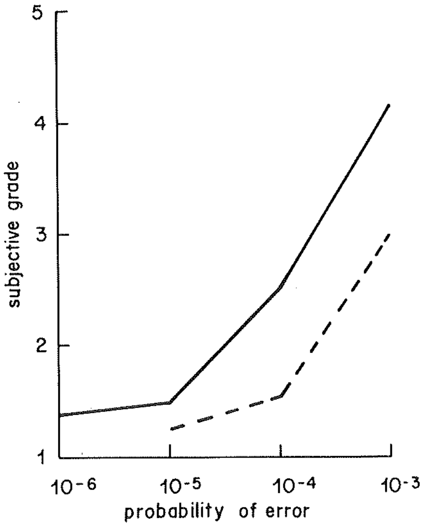

Fig. 9 - Impairment produced by 1 µs burst errors; with error concealment

—— Colour slide picture – – – Pictures from off-air colour film

Subsidiary tests indicated that the method used for concealing burst errors, i.e. the maintenance of constant luminance and chrominance levels during the errors, gave less effective concealment as the duration of the errors increased. More effective concealment of burst errors might well be achieved by other techniques such as the use of information occurring on the previous line.

5. Conclusions

The effect of random errors affecting both single digits and groups (bursts) of digits in a 120 Mb/s video p.c.m. system has been investigated by way of subjective tests. These tests included an examination of an error concealment technique in which the erroneous sample was replaced by the one which occurred 3 sampling periods earlier.

The results indicate that for a high-quality television broadcasting system, the error probability should not be greater than:—

(a) 10^{-7} for unconcealed errors; this figure applies to both single-digit and burst errors of any duration up to at least 1 µs.

(b) 10^{-4} for concealed single-digit errors.

(c) 10^{-5} for concealed bursts errors of any duration up to 1 µs.

The results obtained were compared with the results of tests to determine the impairment caused by drop-outs in video tape recordings. This comparison suggests that the conclusion given above for unconcealed errors still apply to errors on monochrome pictures having burst durations up to 12 µs.

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